

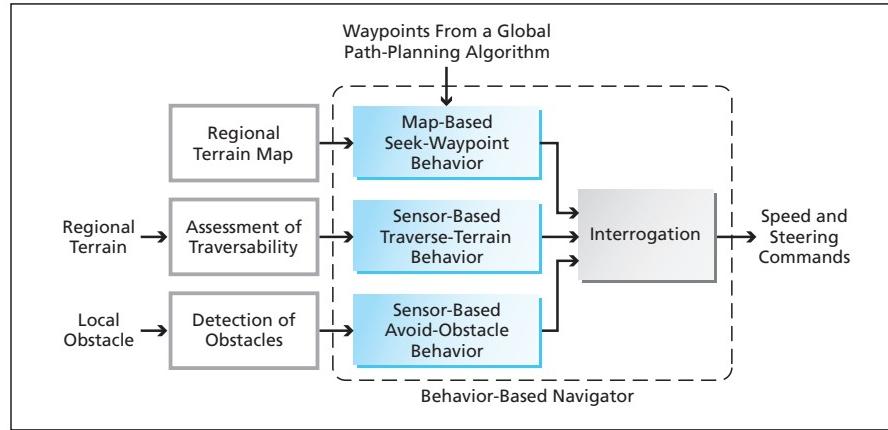


2 Integrating Terrain Maps Into a Reactive Navigation Strategy

Traversability of terrain is taken into account as an integral part of navigation.

NASA's Jet Propulsion Laboratory, Pasadena, California

An improved method of processing information for autonomous navigation of a robotic vehicle across rough terrain involves the integration of terrain maps into a reactive navigation strategy. Somewhat more precisely, the method involves the incorporation, into navigation logic, of data equivalent to regional traversability maps. The terrain characteristic is mapped using a fuzzy-logic representation of the difficulty of traversing the terrain. The method is robust in that it integrates a global path-planning strategy with sensor-based regional and local navigation strategies to ensure a high probability of success in reaching a destination and avoiding obstacles along the way. The sensor-based strategies use cameras aboard the vehicle to observe the regional terrain, defined as the area of the terrain that covers the immediate vicinity near the vehicle to a specified distance a few meters away. The method at an earlier stage of development was described in "Navigating a Mobile Robot Across Terrain Using Fuzzy Logic" (NPO-21199), *NASA Tech Briefs*, Vol. 27, No. 2 (February 2003), page 5a. A recent update on the terrain classification stage of the method was reported in "Quantifying Traversability of Terrain for a Mobile Robot" (NPO-30744), *NASA Tech Briefs*, Vol. 29, No. 7 (July 2005), page 56. To recapitulate: The basic building blocks of the method are three behaviors that focus on successively smaller spatial scales and are integrated (in the sense of



The **Navigation-System Architecture** implements three behaviors that focus on successively smaller spatial scales. These behaviors are integrated to enable safe traversal of rough terrain from a starting point to a destination.

blended) through gains or weighting factors to generate speed and steering commands. The weighting factors are generated by fuzzy logic rules that take account of the current status of the vehicle.

At the present state of development, the three behaviors are denoted as a map-based seek-waypoint behavior, a sensor-based traverse-terrain behavior, and a sensor-based avoid-obstacle behavior (see figure). Navigation is initiated by a global path-planning algorithm, which generates a sequence of waypoints that define an optimal path that passes through safe (that is, sufficiently traversable) regions of the terrain from a starting point to a destination. The waypoints are fed to the map-based seek-waypoint behavior,

which, as its name suggests, seeks to direct the vehicle safely from the starting location to a waypoint. The sensor-based traverse-terrain behavior determines the safest regional segment to traverse on the basis of information from regional terrain images acquired by the cameras. The sensor-based avoid-obstacle behavior involves the use of local-obstacle information from the images to develop steering and speed commands to maneuver the vehicle around the obstacles.

This work was done by Ayanna Howard, Barry Werger, and Homayoun Seraji of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).
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2 Reducing Centroid Error Through Model-Based Noise Reduction

Corrections are made for bias and noise.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method of processing the digitized output of a charge-coupled device (CCD) image detector has been devised to enable reduction of the error in computed centroid of the image of a point source of light. The method involves model-based estimation of, and correc-

tion for, the contributions of bias and noise to the image data. The method could be used to advantage in any of a variety of applications in which there are requirements for measuring precise locations of, and/or precisely aiming optical instruments toward, point light sources.

The principal sources of centroid error are bias and noise in the outputs from the pixels of the CCD. Noise consists mainly of fixed components (readout noise and noise from dark current) and variable components (pixel defects and shot noise from background light).